ABSTRACT

DEVELOPMENT OF A PLUME WITH OFF-SOURCE VOLUMETRIC HEATING

A cumulus cloud is a naturally occurring flow in which buoyancy is generated not only at the surface but also away from it following the release of latent heat during the condensation of water vapour The mechanism governing the flow behaviour in such cases is poorly understood The entrainment hypothesis first conceived by G I Taylor (Morton et al 1956) postulates that the mean inflow velocity across the edge of a free turbulent shear flow is proportional to a characteristic mean velocity within the flow Models that assume entrainment of ambient air into clouds from the lateral edges and employ an entrainment relationship of the above kind fail to make realistic predictions of either liquid-water concentrations or height of penetration for the cloud as discussed by Bhat and Narasimha (1996) The present investigation is an experimental attempt to simulate certain aspects of the flow in a cloud, in particular to study in greater detail the effect of buoyancy enhancement away from the source in a fully developed plume The buoyancy enhancement is achieved by means of volumetric heating Elavarasan et al (1995) made a first attempt in this direction by the study of a volumetrically heated jet

The present study concerns the behaviour of a plume in neutral surroundings with and without buoyancy enhancement The appropriate non-dimensional parameter is the heat release number G, defined by Bhat and Narasimha (1996) relating the volumetric heat input and the energy flux with which the flow enters the heat injection zone in the plume

$$G = \frac{Q\,\alpha\,g\,b_u}{C_p J U}$$

where Q is the total volumetric heat input (in Watts), C_p is the specific heat (Jkg ^{1}K ^{1}), J is the momentum flux (kgm s ^{2}), α is the coefficient of cubic expansion of the fluid (K ^{1}) and g is the acceleration due to gravity In the experiments reported here, this number has been set to the value G=0 25, which is characteristic of conditions in cumulus clouds

The present work involves the study of a jet and a plume both subjected to volumetric heating The results from the study of the unheated (i e without volumetric heating) cases are compared against those reported in the literature The Morton lengthscale of the plume is small enough to ensure that the plume obeys the well known similarity laws before reaching

the region of heat injection The exit Reynolds numbers of the jet and plume are so chosen as to enable them to have the same specific momentum flux at the beginning of the heat injection zone for comparison

The experimental setup generates either a vertical axisymmetric jet or a plume in a glass water tank The enhancement of buoyancy is achieved by a volumetric heat injection method developed by Bhat et al (1989), based on direct ohmic heating of a conducting liquid, also used earlier by Elavarasan et al (1995)

The tank is filled with filtered and de-ionized water to ensure a non-conducting ambient The plume is generated by means of an electric heater enclosed in a perspex heating chamber The active fluid (de-ionized water made electrically conducting by means of addition of hydrochloric acid) is supplied to the plume heating chamber by means of a variable height constant level tank The exit temperature is maintained at 55°C above the ambient by variation of the voltage supplied to the heater The Morton length scale for the flow is about 16mm

Measurements are carried out by means of a two-component Laser Doppler velocimeter Profiles of the mean and turbulent velocity in the axial and radial directions are obtained Measurements are carried out upto a distance of 120 *d* from the exit and specific mass and momentum fluxes calculated therefrom

The structural differences in the flow are examined by the Laser Induced Flouresence visualisation technique, using Rhodamine 6G dye Still photographs as well as video recordings were taken, which are analysed in order to quantify the effects of heating on the structure of the flow

The structure and dynamics of an axisymmetric plume are considerably altered when the buoyancy is enhanced by volumetric heating The spread rate in the heated plume is thus reduced in the upper part of the heat injection zone and just beyond it The velocity scale is strongly affected, and leads to an initial increase in the mass flux followed by a region where it remains constant The specific mass flux at the end of the heat injection zone is seen to be half of what is predicted by using a constant entrainment coefficient for the entire plume as suggested by Turner (1986) The heating, through the disruption of the large eddies, is responsible for a reduction in entrainment

Chapter 1 describes the motivation and the objectives for the work along with a brief introduction to the behaviour of jets and plumes from previous studies Relevant literature regarding earlier efforts to simulate cloud like flows in the laboratory is presented The concept of entrainment is introduced and the various mechanisms for the entrainment process proposed by previous investigators are discussed in detail

The description of the experimental arrangement to generate jet and plume flows is given in Chapter 2 The flow visualisation technique used is described The instrumentation used for making the velocity measurements and their chosen settings is outlined The experimental procedure adopted is detailed A non-dimensional number for quantifying the amount of volumetric heat input to the flow is introduced Finally the various precautions observed in order to ensure the repeatability of the experiment and validity of the fixed experimental conditions over the duration of the run are described

Chapter 3 presents the reults of the experiments on the jet with and without heating The results from flow visualisation are presented here in the form of still photographs of the instantaneous horizontal and vertical sections and discussed Following this the results from the LDV measurements of the axial and radial profiles are presented The half widths of velocity and the mass and momentum fluxes calculated from them are discussed

Chapter 4 presents the results of the experiments on the plume along the lines of Chapter 3 The discussion of the flow visualisation photographs is followed by the presentation and discussion of the results from the LDV measurements

A digital analysis of the flow visualisation videos is presented in Chapter 5 The various methods tried for the quantification of the effect of volumetric heating on the structure of the flow are first described, followed by a detailed discussion of the results and their implications

Chapter 6 ends the thesis with a summary of the results obtained and the conclusions drawn along with some suggestions for extension of the work

Appendix A describes the ohmic heating technique used in the study

Appendix B derives the non-dimensional heat release number used to quantify the effects of volumetric heating on the flow